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A teaching machine presents a series of problem materials to a student, requires an overt behavioral response, and provides results of the behavior immediately following the response. There were eight groups of ten junior college students who were experimentally trained with manually controlled teaching machines; each group was taught with a different mode of teaching machine operation. The three independent variables were student response mode, size of steps between successive items, and sequencing (branching) procedure. A written criterion test was given to the experimental groups immediately after the training sessions and again three weeks later. The same criterion test was given to a control group who came from the same school classes as the experimental groups but who had no training on the concepts taught to the experimental groups. Dependent variables were the required teaching machine training time and scores on the criterion test. Scores on a pretest were used as a control variable. Results were that the use of the machine led to significant learning by the experimental groups; the multiple-choice response mode took less time than the constructed response mode; small items required more training time, but yielded higher test scores; and branching conditions required less training than nonbranching, but were not obtained on the total criterion test among experimental groups. Tables delineated the different test scores.

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INSTRUCTIONAL TECHNOLOGY - U.S.C

EFFECTS OF THREE VARIABLES IN A TEACHING MACHINE

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Recently a number of automated teaching devices, or "teaching machines," have been developed to assist human instructors in the fields of education and training. A "teaching machine" may be defined as a device which (*a*) presents a series of problem materials (questions) to a student; (*b*) requires the student to respond to each question by some overt behavior; and (*c*) provides the student with knowledge of results of his behavior, usually immediately following each response.

The purpose of the present study is to investigate three variables related to the design of teaching machines:

1. Student Response Mode. The multiple choice and constructed response[1] modes of operation are compared for teaching effectiveness. Considerable discussion of the relative merits of these modes can be found in the literature (Pressey, 1959; Skinner, 1958).

2. Size of Item Step. Most investigators in the field of automated teaching agree that optimal learning occurs when items presented to the student give the student a large degree of support (Glaser & Homme, 1958; Porter, 1958; Skinner, 1958). According to these investigators, the items should be worded and sequenced in such a way that the student finds it simple to proceed from one item to the next, and thus receives a large percentage of positive reinforcements. In the present study, an attempt was made to evaluate experimentally the extent of the purported superiority of the small step condition.

3. Item Sequence Control. The great majority of existing teaching machines present subject material items in an essentially predetermined sequence. In the present study a predetermined item sequence was compared with a more adaptive procedure (called "branching") in which a student who had already learned a concept was allowed to skip certain other items covering the same concept.

[1] The term "constructed response" refers here to the procedure in which the student must complete statements by filling in (constructing) one or more missing words.

METHOD

The experiment consisted of three phases: (*a*) A training session for each of 80 experimental *Ss* with a 'teaching machine' operating under one of eight different teaching procedures being compared; (*b*) A criterion test given to each *S* immediately following the training session; and (*c*) The same criterion test, given approximately three weeks after the training sessions to the 80 *Ss* and also to a control group of 104 students who were in the same classes with the *Ss*, but who did not receive teaching machine training.

Although the teaching machine training session for any single experimental *S* required less than two hours, the sessions for all *Ss* extended over a period of one week. During this week, the training sessions replaced regular classroom studies for the experimental *Ss*, while the control group continued to receive its normal instruction. Subject material for the classroom instruction during this week, and up to the final administration of the criterion test, was not closely related to the material taught with the teaching machines.

The purpose of the control group was to provide a comparison between experimental *Ss* and other students who did not receive any type of training on the particular concepts covered by the *Ss* in their teaching machine training. From such a comparison it is possible to determine whether significant learning has occurred in the experimental group as a whole.

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The following experimental performance measures were recorded for each *S*, regardless of mode of instruction: (*a*) time required to finish training; (*b*) score on multiple choice portion of criterion test; (*c*) score on constructed response portion of criterion test.

A psychology pretest administered prior to the experiment provided a measure of individual differences in initial achievement among the students at the start of the experiment. This pretest was given as part of the regular course work to all students in the psychology classes from which *Ss* and controls were drawn, and was not closely related to the experimental materials. Pretest items were concerned primarily with the history of psychology.

Apparatus

Six identical sets of equipment were used in the experimental training sessions. The sets constituted manually controlled teaching machines, with human experimenters used in place of automatic control mechanisms. Each set consisted of a wooden screen, a number of pushbuttons and lights used for communication between experimenter and *S*, a deck of 5 x 8 cards containing instructional items, and three sheets (panels) with information relating to the instructional items. The wooden screen had a window in its center in which the *E* placed cards so the instructional items could be seen by the *S*. Information sheets were attached to the *S*'s side of the screen during experimental training sessions, and could be used by the *S* as an aid in answering the instructional item; *Ss* could not use the sheets while taking the criterion quiz, however.

Each of the six teaching machines could be operated under any one of eight teaching procedures. These eight teaching procedures represent the eight combinations of three experimental variables, each variable having two possible values as follows: (*a*) response mode (multiple-choice versus constructed response); (*b*) size of steps between successive items to be taught (small steps versus large steps); and (*c*) type of item sequence control (branching versus nonbranching).

Procedures

Ss and *Es* were randomly assigned to the eight experimental training conditions, using random number tables, with the restriction that 10 *Ss* were trained under each condition. *Es* were reassigned after each session, so that no *E* was restricted to a single experimental condition.

Printed instructions were read aloud to each *S* before the start of the training session. These instructions described the task to be performed by the *S*, and informed him that both accuracy and speed of learning were important.

Constructed Response versus Multiple-Choice Operation. In the constructed response mode of operation the *E* placed in the window of the screen a card with a constructed response item containing one or more blank spaces to be filled in by the *S*. After the *S* wrote his answer on a slip of paper, the *E* revealed to the *S* the correct answer to the item. The *S* compared his own answer against the correct answer, and signalled by pushbutton whether or not he got the item correct.[3] The *E* removed this card and went on to the next card, continuing until he had finished the deck. He then repeated the entire process, but this time used only the items missed by the *S* on the first trial. The procedure was continued through successive trials until the *S* had answered every item correctly.

In the multiple-choice mode the *S* used

[3] An informal check was made to determine the dependability of the *Ss*' evaluation of their own responses. Several randomly selected *Ss* were observed during training, and after training their slips were compared with the correct answers. Results of the check indicated that *Ss* were generally accurate in their evaluations.

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one of five pushbuttons to indicate his answer to the multiple choice items presented to him. In addition, there were two pushbuttons used by the *E* to tell the *S* whether he had selected a correct or incorrect response. The *S* was required to continue to respond to an item until he had selected the correct answer, upon which the *E* replaced that item with the next in the deck. After he had completed the first trial (e.g., the first run through the deck), the *E* continued with additional trials as required, each time using only the cards that the *S* missed in his first response on the preceding trial.

Small Steps versus Large Steps. Some *Ss* were trained with instructional decks containing many (104) items. These decks were called Small Step decks, because they supposedly require little effort on the part of the *S* to answer a particular item once he has gone through the preceding items. Other *Ss* were trained with Large Step decks containing fewer (56) items, and ostensibly requiring more effort to answer successive items.

From the standpoint of the operation of the teaching machines, there were no procedural differences between Small Step decks and Large Step decks, except in the number of items presented to the *S*.

Branching versus Nonbranching. This variable determined the sequence in which items were presented to the *S*. In the Nonbranching mode, the *E* simply went through all the cards of the deck in order. In the Branching mode, certain items were removed from the deck if the *S* answered certain other items correctly on the first try. The items to be removed were taken out of the deck by a second *E*, so they were never presented to the *S*. Thus, in the Branching mode, the exact number and sequence of items were not fixed, but depended on the performance of the *S*. A more complete description of the criteria for omitting items is given in the following section on instructional materials.

Instructional Materials

The eight item sets (decks) and the three instructional sheets used in the experiment were based on a portion of a college course in elementary psychology used at Harvard University. The first item set obtained was the constructed response, Small Step deck, without branching. This set consisted of the first 104 items from a larger series of items developed at the Harvard University Psychological Laboratory. The remaining seven sets represent combinations of the following transformations of the original items:

1. A number of possible alternative answers were provided for each item, to make the Multiple-Choice decks.

2. Certain items were eliminated from the original set of 104 items, to make the Large Step decks of 56 items. The items eliminated were judged to be largely redundant, in the sense that they related to concepts already covered by other items, and added little extra information.

3. To make the Branching decks, coded instructions for the branching procedure were marked on the backs of certain cards. These instructions indicated which cards were to be eliminated from the deck during the experiment if the *S* correctly answered the marked cards. For convenience, a marked card will be referred to as a Branch card; the cards to be eliminated when a Branch card is correctly answered will be called Conditional Skip cards. In general, a Branch card was the first of several items in the deck covering a particular concept, while the associated Conditional Skip cards consisted of the remaining items covering essentially the same concept. Small Step branching decks included 13 Branch cards and 39 Conditional Skip cards, while Large Step branching decks included 12 Branch cards and 22 Conditional Skip cards.

The three instructional sheets, or "panels" used in the study covered most of the major concepts presented in the instruc-

tional items, but in the form of definitions and brief descriptive materials.

Criterion Test

The criterion test consisted of 36 questions, of which 19 were constructed response (fill-in) and 17 were multiple-choice. All of the questions were based upon the material contained in the original (constructed response; small step; without branching) set of instructional items. The person who prepared the criterion items had not seen the other seven item sets prepared for instruction; conversely, the persons preparing the alternate item sets had not seen the criterion questions.

None of the criterion questions were duplicates of instructional items, though many of the same words were used as correct responses. Most of the criterion questions were of the application type, in which a situation is presented and the respondent identifies the principle involved or attempts to explain or predict an outcome.

Reliability of the criterion test, as estimated by the application of Kuder-Richardson Formula 20 to the scores of the experimental *Ss*, was as follows: (*a*) whole test, .89; (*b*) constructed response portion, .85; and (*c*) multiple-choice portion, .79. Test-retest correlations for experimental *Ss* were .81 for the whole test, .79 for the constructed response portion, and .58 for the multiple choice portion.

Experimental Subjects

The 80 experimental *Ss* and the 104 members of the control group were taken from beginning psychology classes in Santa Monica City College. They had been in the psychology course for about one month, using F. Ruch's *Psychology and Life* as a text and covering some general background in the area of psychology, but had not been given specific instruction in any material closely related to the subject material used in the experiment.

Results

1. Table 1 provides a comparison of mean scores and standard deviations for

TABLE 1

Comparison of Scores for Experimental and Control Groups on Pretest and Criterion Tests

Source of Scores		Experimental Group (N = 80)		Control Group (N = 104)		Experimental Group Minus Control Group		
		Mean	*SD*	Mean	*SD*	*t*	*df*	*P*
Pretest		45.51	8.00	44.41	7.71	1.00	182	Not significant
Criterion test: First admin.	Constructed response	13.50	3.92	7.53	3.62	11.06	195	.01
	Multiple choice	11.62	2.50	9.44	2.36	6.06	195	.01
	Total criterion	25.12	5.93	16.97	5.23	9.99	195	.01
Criterion test: Second admin.	Constructed response	13.40	3.39	Not administered		Not applicable		
	Multiple-choice	12.40	2.52					
	Total criterion	25.80	5.30					

experimental *Ss* and controls on the psychology pretest. No significant difference was obtained between the 80 *Ss* and the 104 controls. The maximum score possible on the pretest was 61.

2. A comparison of mean scores and standard deviations for experimental *Ss* and controls on the posttraining criterion test is shown in Table 1. This criterion test consisted of two subtests, one with multiple choice items, the other with constructed response items. Maximum possible scores were 19 and 17 for the constructed response and multiple choice subtests respectively. Table 1 shows that the experimental group was superior to the control group on the total criterion and on both the multiple choice and constructed response subtests. Differences were significant at the .01 level.

3. The criterion test was readministered to the experimental *Ss* three weeks after the first administration as a measure of retention. No significant difference was obtained on the total criterion (multiple-choice plus constructed response), when the mean of the first administration was compared with the mean of the second administration. On the multiple choice criterion subtest, however, retest scores were significantly higher (.01 level) than original test scores.

The evidence from these first three analyses indicates that the automated teaching materials used with the experimental *Ss* resulted in significant learning of the concepts taught and that this learning is retained at least for a three week period. These findings do not mean that the experimental *Ss* exceeded groups receiving conventional classroom instruction on the same materials, since the control group was not taught the same concepts as the experimental group.

4. Whereas Table 1 concerns differences in performance between the control group and the experimental *Ss* as a whole, the remainder of the tables presented in this report relate to differences among the various experimental treatments. Table 2 shows the results of covariance analyses of the criterion test scores for the eight experimental groups, with pretest scores used as a control variable. The desirability of using the pretest control is indicated by the correlations between pretest and posttest scores, which were as follows: (*a*) .411 between pretest and constructed response criterion scores, (*b*) .404 between pretest and multiple choice scores, and (*c*) .442 between pretest and total criterion.

(*a*) *Constructed Response Criterion Subtest*. The analysis of covariance represented in Table 2 shows a significant main effect for the size of step factor (.05 level of significance), in the direction of higher scores for small step trainees. A significant interaction was also found between the mode of response and branching variables (.05 level). The assumption of homogeneity of regression was tested and found to be satisfied.

Table 3 shows adjusted mean constructed response criterion scores and standard deviations for comparison of the three experimental variables. It also shows the adjusted mean scores and standard deviations for the four combinations of response mode and branching procedure, since this interaction was found significant in the covariance analysis.

(*b*) *Multiple-Choice Criterion Subtest*. Covariance analysis yielded no significant main effects or interactions among the experimental groups on the multiple choice subtest.

(*c*) *Total Criterion Test*. No significant main effects or interactions were obtained among the experimental groups, as determined by covariance analysis.

5. An analysis of variance of differences among the eight experimental groups with respect to the amount of time taken to complete training was also performed. All three main effects are significant at the .01 level. The constructed response training condition took more time than the multiple choice condition; the small step condi-

TABLE 2

COVARIANCE ANALYSIS OF CRITERION SCORES USING A PSYCHOLOGY PRETEST AS A CONTROL

(N = 80)

Source of Variation	Degrees of freedom			*ms*			*F*		
	Constructed Response	Multiple-Choice	Total Criterion	Constructed Response	Multiple-Choice	Total Criterion	Constructed Response	Multiple-Choice	Total Criterion
A: Mode of response	1	1	1	29.22	10.22	72.15	2.48	1.94	2.65
B: Size of step	1	1	1	46.99	9.20	99.96	3.99*	1.74	3.68
C: Branching	1	1	1	1.27	.99	4.65	.11	.19	.17
AB	1	1	1	11.05	15.66	54.73	.94	2.97	2.01
AC	1	1	1	53.28	.82	65.84	4.52*	.16	2.42
BC	1	1	1	18.34	.03	18.35	1.56	.01	.67
ABC	1	1	1	2.23	1.03	5.57	.19	.26	.20
Within cells	71	71	71	11.93	5.28	27.19			
Total	78	78	78						

* .05 level of significance.

TABLE 3

ADJUSTED MEAN SCORES ON CONSTRUCTED RESPONSE CRITERION SUBTEST FOR DIFFERENT TRAINING CONDITIONS

Training Mode	*N*	Adjusted Mean Scores on Constructed Response Subtest	*SD*
Constructed response	40	14.14	3.35
Multiple-choice	40	12.86	4.31
Small step	40	14.31	4.02
Large step	40	12.69	3.72
Branching	40	13.21	4.26
No-branching	40	13.79	3.58
Branching with constructed response	20	12.93	3.53
Branching with multiple-choice	20	13.50	4.98
No-branching with constructed response	20	15.35	3.36
No-branching with multiple-choice	20	12.92	3.45

tion took more time than the large step condition; and the nonbranching condition took more time than the branching condition. Interactions were not significant. The mean scores and standard deviations on the time criterion are shown in Table 4

TABLE 4

MEAN TIME REQUIRED FOR TRAINING UNDER DIFFERENT MODES

Training Mode	Training Time (Minutes)	*SD* (Minutes)
Constructed response	54.38	10.64
Multiple-choice	44.38	10.92
Small step	57.28	9.19
Large step	41.48	7.60
Branching	43.78	9.94
No-branching	54.98	10.55

Note.—N for each training mode is 40.

TABLE 5

ANALYSIS OF VARIANCE OF TIME REQUIRED TO COMPLETE TRAINING

Source of variation	*ss*	*df*	*ms*	*F*
A (Mode of response)	2000.00	1	2000.00	11.66*
B (Size of step)	4992.80	1	4992.80	29.11*
C (Branching)	2508.80	1	2508.80	14.62*
AB	42.05	1	42.05	.25
AC	48.05	1	48.05	.28
BC	162.45	1	162.45	.95
ABC	540.80	1	540.80	3.15
Within cells	12347.80	72	171.50	
Total	22642.75	79		

* .01 Level of significance.

and the analysis of variance is summarized in Table 5.

Discussion

Constructed Response Criterion Data

Size of Step Variable. The finding that treatment groups given more items (small steps) learned more than groups receiving few items is in accord with B. F. Skinner's (1958) emphasis on the importance of small steps in writing instructional item sets. The superiority of small steps in total amount learned must be weighed, however, against the significantly greater training time required by small step trainees than by large step trainees. The best choice of item step size for any applied teaching situation will be determined in part by the extent to which required training time is a critical consideration.

Branching Variable. In the comparison of large item steps and small steps it was found that small step trainees, who were given more items, learned more than large step trainees. In view of this finding it is notable that branching, with its consequent reduction in total number of items presented, did not differ significantly from nonbranching in amount taught, though there was a suggestive difference in favor of nonbranching. Probably an important factor in this finding was the way in which items were eliminated in the branching procedure. An item was skipped only after the trainee had demonstrated some knowledge of the concept taught by that item, with the result that every major concept was covered by at least one item. At the same time, the branching procedure made possible a significant decrease in required training time, as compared with the nonbranching procedure.

When both the amount learned and the required training time are considered, the branching procedure appears to offer an overall advantage over nonbranching. The present investigators feel, moreover, that branching, or other types of control flexibility, offer even greater potential for future improvement in teaching machine effectiveness. In the study reported here, limitations due to human operation of the teaching machine control mechanism placed heavy restrictions on the branching procedure. The greatly simplified skipping procedure resulted in a significant advantage in training time but not in amount learned. More complex forms of control flexibility, using some type of automatic equipment, may prove superior to predetermined sequence control in both amount learned and speed of learning.

Response Mode Variable. Under the conditions of the experiment reported here, student response mode did not significantly affect the amount learned by the students. Since required training time was significantly less for multiple-choice trainees than for constructed response trainees, the overall advantage appears to be with the multiple-choice mode. It is possible, of course, that the results would be different under other experimental conditions, and further research in the area may prove valuable.

Response Mode-Branching Interaction. The significant interaction between response mode and branching procedure can probably be attributed to the combined effects of two factors, neither of which is sufficiently powerful to have statistically significant effect when taken separately. The first factor contributing to the interaction is the number of items presented to the *S*s. By this hypothesis the constructed response trainees learned more without branching than with branching because the branching procedure caused a reduction in the total number of items. The second factor contributing to the interaction effect was the relation between the response mode required in the training session, and that required in the criterion test. This might well be expected to give an advantage to the constructed response trainees due to generalization decrement on the part of the multiple-choice trainees.

Main effect differences in favor of the nonbranching and constructed response conditions, though nonsignificant, tend by their direction to support the "combined effects" interpretation presented here.

Multiple-Choice Criterion Data

Although the mean of the experimental *Ss* on the multiple-choice criterion significantly exceeded the control group mean, no significant differences were obtained among the different experimental groups. Differential effects of the various experimental treatment combinations on the multiple-choice criterion appear to have been masked by a larger effect common to all experimental groups. This masking error variance can probably be attributed to the nature of the multiple-choice criterion subtest. Of the 17 multiple-choice items, nine had four alternatives, two had three alternatives, and six had only two alternatives. The probability of obtaining correct answers on a chance basis could account on the average for approximately one-third of the items. The largest portion of the variance of the scores on the multiple-choice test may be due to this chance factor. Students of the sort used in the study are usually highly skilled in picking out subtle specific determiners by which they can eliminate implausible alternatives on grounds other than factual content. These skills, which together with day-to-day fluctuations in individual performance are treated as systematic variance in the Kuder-Richardson method of estimating reliability, contribute to over-estimation of the effective reliability of the test. In this case, the Kuder-Richardson reliability estimate was .79. A more realistic estimate of reliability is given by the multiple-choice criterion test-retest correlation, which was only .58.

Total Criterion Test Data

The results of the analysis of the total criterion follow from the results obtained on the analyses of the two subtests. Error variance in the multiple-choice portion of the total criterion appears to have masked intergroup differences so that these differences are not significant. It can be noted in Table 2 that the covariance F test approaches but does not reach significance at the .05 level for both the size of step factor and the mode of response-branching interaction.

Time Criterion

Differences in required training time are generally in the expected direction. Small step groups and nonbranching groups took longer than large step and branching groups because they were required to answer more questions. The fact that constructed response groups took longer than multiple-choice groups indicates that the composition and writing of answers is more time consuming than the recognition of a "correct" solution among several alternatives, even though multiple-choice trainees were sometimes required to make several selections before choosing the right answer.

Summary

Eight groups of ten junior college students were given an experimental training session with manually controlled teaching machines, each group being taught with a different mode of teaching machine operation. The three independent variables were: (*a*) student response mode, (*b*) size of steps between successive items, and (*c*) sequencing (branching) procedure. A written criterion test was given to all *Ss* immediately after the training session, and again three weeks later. The same criterion test was given to a control group which came from the same school classes as the experimental *Ss* but which had no training on the concepts taught in the experimental sessions to the *Ss*. Dependent variables were the required teaching machine training time and scores on the criterion test. Scores on a pretest were used as a control

variable in a covariance design. Major results were as follows:

1. Use of the simulated teaching machine led to significant learning by the *Ss*, as determined by comparison with the control group.

2. The multiple-choice response mode took significantly less time than the constructed response mode. No significant difference was obtained between response modes on the criterion test.

3. Small item steps required significantly more training time, but also yielded significantly higher test scores than large item steps on the constructed response criterion subtest.

4. The branching conditions required less training than nonbranching, but were not significantly different on the criterion test. A significant interaction was obtained between the mode of response and branching variables on the constructed response criterion. This interaction resulted from a high mean criterion score obtained by the constructed response—nonbranching group.

5. No significant differences were obtained among the experimental groups on the multiple-choice criterion subtest, or on the total (multiple-choice plus constructed response) criterion test.

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